Small Loop Antennas

Michelle Paquette, AA6MP

What makes a good antenna?

- Efficient radiation of RF power
- Good match to transmitter for best power coupling

Antenna Radiation

- Electric charge under acceleration will produce electromagnetic radiation
- A constantly varying magnetic field will produce electromagnetic radiation
- Maxwells Equations - a set of four equations that govern electric and magnetic fields

Maxwell's Equations

1. $\nabla \cdot \mathbf{D} = \rho_V$

2. $\nabla \cdot \mathbf{B} = 0$

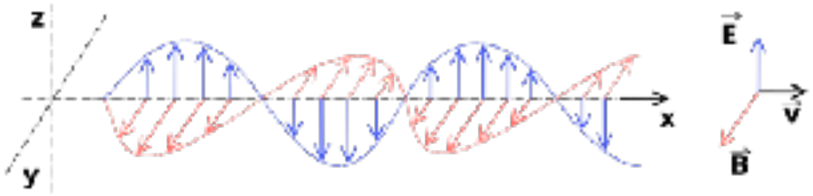
3. $\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$

4. $\nabla \times \mathbf{H} = \dfrac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$

1 and 2 show electric and magnetic field divergence
3 and 4 show curl, or the way the fields wrap around a generator
3 is Faraday's Law, and shows the electric field curl is proportional to the rate of change of the magnetic field with respect to time. That is, a changing magnetic field gives rise to a changing electric field.
4 is Ampere's law, and shows magnetic field curl is proportional to the rate of change of the electric field with respect to time. That is, a changing electric field gives rise to a changing magnetic field.

Maxwell Radiates!

- A changing magnetic field gives rise to a changing electric field
- A changing electric field gives rise to a changing magnetic field
- This gives us a self-propagating set of fields!



So, if a changing electric field gives rise to a changing magnetic field, and a changing magnetic field gives rise to a changing electric field…

Mention that a changing magnetic field can also be used to start this, the mag loop antenna principle!

Antenna Efficiency

- **For an antenna to be efficient, we want it to radiate most of the power we send to it**
- **Transmitter power that heats the wiring doesn't contribute to radiating!**

Efficiency and Impedence

- A low impedance gives us lots of current, but with a lower voltage change over the antenna.
- That means less acceleration of charge, but more charge being accelerated, and so a wash for radiated power
- But… low impedance means higher currents

$P_{resistive} = I^2R$ … wiring and ground losses!

Compact Antennas

- **Antenna efficiency tends to drop for sizes below 1/8 wavelength.**
  - **Smaller charge under acceleration**
  - **Less acceleration from voltage gradient**
  - **More losses in matching mechanisms and ground**

There ain't no such thing as a free lunch!

Small Loop Antennas

- Length much smaller than 1 wavelength
- Very low radiation resistance or impedance
  - Raises the significance of DC or resistive losses
  - High reactance needs to be cancelled out
- Radiation patterns not intuitive

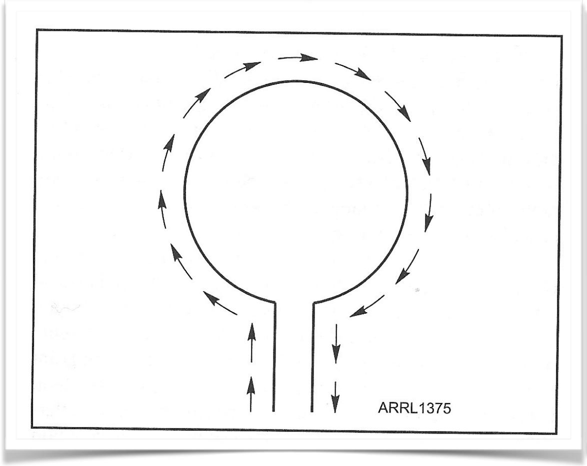
The antenna presents a very low radiation resistance or impedance, so ordinary resistive losses in wire may equal or exceed the radiation resistance. That means more power turns into heat and less is radiated. The antenna is not naturally resonant, so matching it to the transmitter is trickier. Finally, the radiation pattern is counterintuitive.

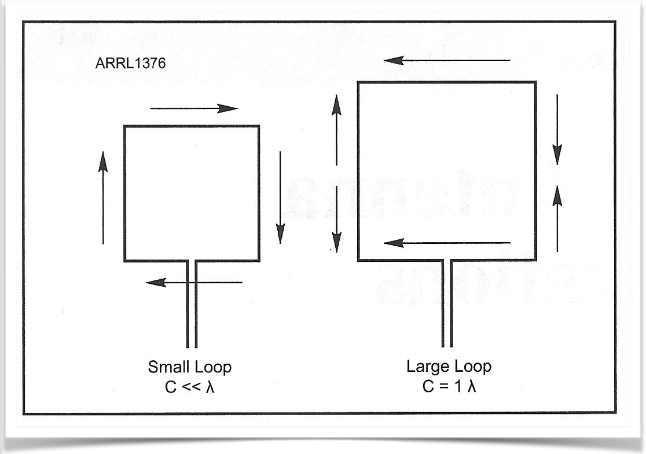
Small Loop Antennas

- The length is typically on the order of 1/10 wavelength.
- The RF current flowing around the loop is effectively equal in phase and amplitude at all points around the loop
- The fields generated cancel out broadside to the loop!

Small Loop Antennas

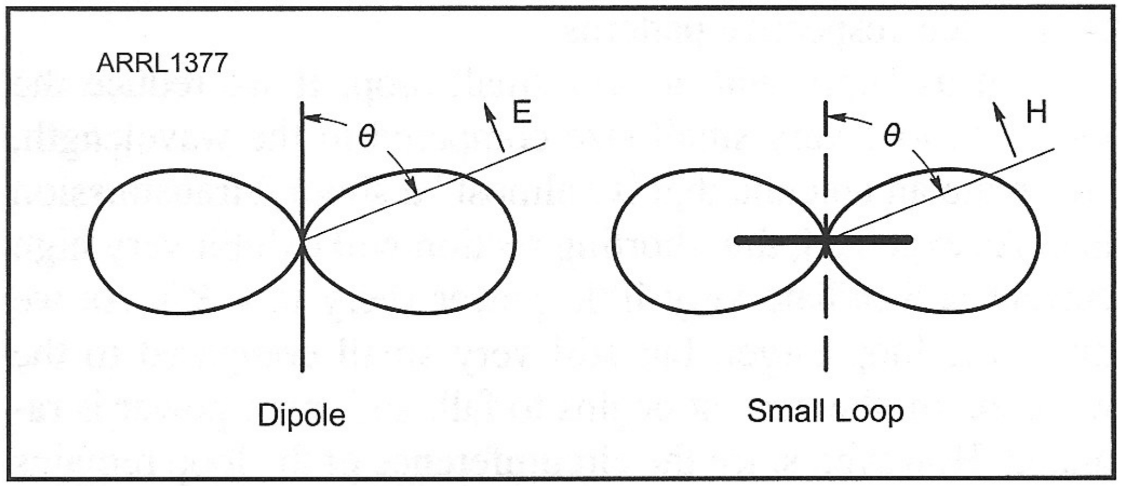
The length is typically on the order of 1/10 wavelength, so the RF current flowing around the loop is effectively equal in phase and amplitude at all points around the loop





Small Loop Antennas

Broadside, all parts of the loop are equally distant from the measurement point, and the fields all cancel out!



WIth a dipole, the electric field is strongest broadside to the element. With our small ‘magnetic’ loop, the files is minimal broadside to the loop, and maximum in the plane of the loop! The antenna has very pronounced NULLs at right angles to the loop.

Small Loop Antennas

- **Antenna efficiency is given by the radiation resistance divided by the sum of radiation and loss resistance.**
- ***Efficiency*** $= R_r / (R_r + R_l)$

Losses are things like DC resistance of the wiring, dielectric losses in any insulation, and so on.

Small Loop Antennas

- **Ohm's Law gives us a power equation**

$$R = P / I^2$$

- **If we sum up the radiated power from our loop and integrate this with the current we get:**

$$R_r = 31{,}200 \; (A / \lambda^2)^2$$

- **A is area of our loop, and ƛ is our operating wavelength**

Radiation resistance is proportional to the area of the loop squared at any given wavelength. Smaller loops have less radiation resistance, making even small losses use up more of our total power

Small Loop Antennas

- Area is not particularly convenient, but it is proportional to the radius, diameter, or circumference squared. We usually know how much conductor makes up the antenna circumference.

$$R_r = 197\,(C / \lambda)^4$$

- C is the circumference of our loop, and λ is our operating wavelength

Small Loop Antennas

$$R_r = 197\,(C / \lambda)^4$$

- **Even a small change in circumference can greatly change the radiation resistance.**
- **We want radiation resistance R_r high compared to the loss resistance R_l for best efficiency.**

$$\text{Efficiency} = R_r / (R_r + R_l)$$

Small Loop Antennas

$$\text{Efficiency} = R_r / (R_r + R_l)$$

- Making the loop larger improves efficiency
- Reducing resistive losses, as with a larger diameter conductor, improves efficiency
- Minimizing ‘skin effect’ losses also helps

Small Loop Antennas

Efficiency = $R_r / (R_r + R_l)$

- **Adding turns (n) to the loop raises radiation resistance, improving efficiency**

$$R_r = 197\, n^2\, (C / \lambda)^4$$

- **Adding a high permeability core (υ_{er}) such as ferrite improves efficiency as well**

$$R_r = 197\, n^2\, \upsilon_{er}^2\, (C / \lambda)^4$$

More turns, the same method used to raise inductance of a coil, raises radiation resistance and improves efficiency.

Small Loop Antennas

- **Both of these are 'small loop' antennas!**

In terms of sheer quantity, the ferrite core loop antenna is the most popular, being found in millions of AM radios.

They do not work so well for transmitting, as something called the 'proximity effect' between loop turns increases skin effect losses;

Small Loop Antennas

- **Adding turns (n) to the loop raises radiation resistance, improving efficiency…**
- **But, when transmitting, the *proximity effect* between loop turns increases skin effect losses**
  - **An 8 turn loop with calculated 10% efficiency may have just 3% efficiency when *proximity effect* is considered.**

Small Loop Antennas

- When transmitting at 100 watts, currents of 10s of amperes may be developed
- Voltages of several thousands of volts or more may be developed across tuning capacitors
- These also contribute to losses, and manufacturing costs, as large conductors and welded connections are needed

Small Loop Antennas

- Multi-turn loops with these voltages and currents are not all that practical
- A ferrite core is easily saturated by transmission strength magnetic fields, and will distort the signal with a nonlinear response unless much larger than commercially practical
    - Experiments have been done with 2.2 cubic foot ferrite cores, over 600 pounds, at 2 MHz, but efficiency remained below 3%. These cores were still limited to 5 watts.

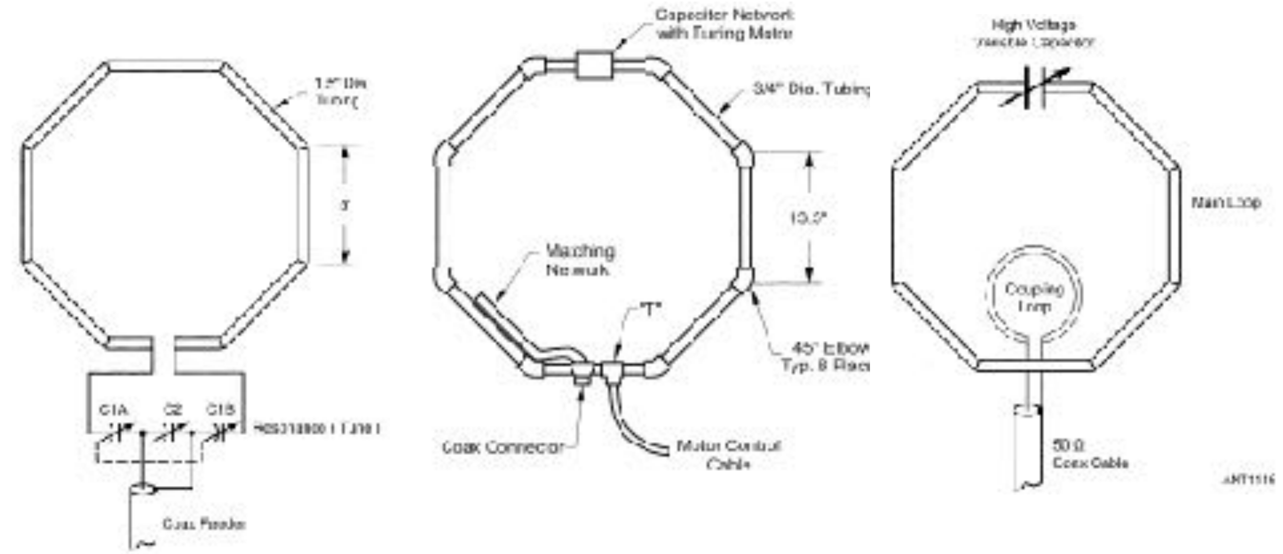
Small Loop Antennas

$$R_r = 197\, n^2\, \upsilon_{er}^2\, (C / \lambda)^4$$

$$\text{Efficiency} = R_r / (R_r + R_l)$$

- **The biggest factor raising radiation resistance is the loop circumference**
- **Even small resistive losses, as from the capacitor contact wipers (0.02 Ω), has a huge impact with low radiation resistance (0.1 Ω).**

Small Loop Antennas



Army Loop **W5QJR/Hart Loop** **Coupling Loop**

Small Loop Antennas

- Even with just 100 watts of transmitter power, voltages of several thousand volts and circulating currents of 30 amps or more can be developed in a 3’ diameter loop, with circulating reactive power in excess of 100 KVA!

- Care is needed in the construction and operation of these small antennas.

Small Loop Antennas

Demonstration

- Equipment setup
- Operation and tuning of the loop
- Bandwidth, using analyzer spectrum sweep

Question Time

- Any questions on tonight's topic?
- Any pithy commentary?